# PRESENT UNDERSTANDING OF THE
# NUCLEON SPIN STRUCTURE*

A. METZ

*Institut für Theoretische Physik II,*
*Ruhr-Universität Bochum, 44780 Bochum, Germany*
*E-mail: metza@tp2.ruhr-uni-bochum.de*

The present understanding of the spin structure of the nucleon is briefly reviewed. The main focus is on parton helicity distributions, orbital angular momentum of partons as defined through generalized parton distributions, as well as single spin asymmetries and time-reversal odd correlation functions.

## 1. Introduction

The history of the non-trivial nucleon spin structure started already in 1933 with the discovery of the anomalous magnetic moment of the proton by Frisch and Stern [1]. This observation led to the important conclusion that the nucleon cannot be pointlike.

In the meantime the field has grown tremendously. This short review concentrates on the QCD spin structure of the nucleon which is usually quantified in terms of various parton distributions. In this context one is dealing with three kinds of parton distributions: (1) forward distributions (quark and gluon helicity distribution), (2) generalized parton distributions (GPDs) which contain information on the orbital angular momentum of partons, (3) transverse momentum dependent distributions (TMDs) which can lead to single spin asymmetries (SSAs). Related experiments are currently running at CERN, DESY, Jefferson Lab, and RHIC.

Many issues like the transversity distribution [2], parton distributions for $x \to 0, 1$, various sum rules, subleading twist etc. cannot be covered. For such topics the reader is referred to existing review articles (like, e.g., Refs. 3–6) and referenes therein, as well as these proceedings.

2

## 2. Parton helicity distributions

### 2.1. *Quark helicity distribution*

Up to now our knowledge about the quark helicity distribution $\Delta q$ has mostly come from inclusive lepton scattering off the nucleon. By measuring double spin asymmetries (polarized lepton beam and polarized target) one can extract the structure function $g_1(x, Q^2)$ which is given by

$$g_1^{p,n} = \frac{1}{9}\Delta\Sigma \pm \frac{1}{12}\Delta q_3 + \frac{1}{36}\Delta q_8 \,, \tag{1}$$

with the flavor combinations

$$\begin{aligned}
\Delta\Sigma &= (\Delta u + \Delta\bar{u}) + (\Delta d + \Delta\bar{d}) + (\Delta s + \Delta\bar{s}) \,, \\
\Delta q_3 &= (\Delta u + \Delta\bar{u}) - (\Delta d + \Delta\bar{d}) \,, \\
\Delta q_8 &= (\Delta u + \Delta\bar{u}) + (\Delta d + \Delta\bar{d}) - 2(\Delta s + \Delta\bar{s}) \,.
\end{aligned} \tag{2}$$

In the past many QCD analyses, using (slightly) different assumptions and different schemes, of polarised DIS data were performed. Information on the first moment of $\Delta q_3$ and $\Delta q_8$ from beta decay of the neutron and hyperons usually serves as an important independent constraint. The results of such QCD analyses can roughly be summarized as follows: while $\Delta\Sigma$ and $\Delta q_3$ are fairly well known, $\Delta q_8$ is not known with the same accuracy. In particular, this means that there still exists a considerable uncertainty for the distribution of strange quarks. Most importantly, however, inclusive DIS measurements do not permit to determine $\Delta q$ and $\Delta\bar{q}$ separately.

At this point additional information can be obtained from semi-inclusive DIS where one extracts the double spin asymmetry

$$A^h \propto \frac{\sum_q e_q^2 \, \Delta q(x) \, D_q^h(z)}{\sum_q e_q^2 \, q(x) \, D_q^h(z)} \,. \tag{3}$$

Detecting one hadron $h$ in the final state not only addresses the distribution of specific quark flavors (e.g., by looking at kaons one can learn something about the strange-quark distribution), but also makes it possible to separate the quark and antiquark distributions, since the fragmentation functions $D_q^h$, $D_{\bar{q}}^h$ put different weights on $\Delta q$ and $\Delta\bar{q}$. The results for such an analysis from the HERMES Collaboration [7,8] are shown in Fig.1, where, in particular, it turned out that the data are consistent with a vanishing sea quark distribution for all three flavors. It has been claimed, however, that the extraction method used in Ref. 7 has some model dependence [9]. Recently, there has been quite some activity aiming at an entirely model-independent analysis of semi-inclusive DIS data [10,11].
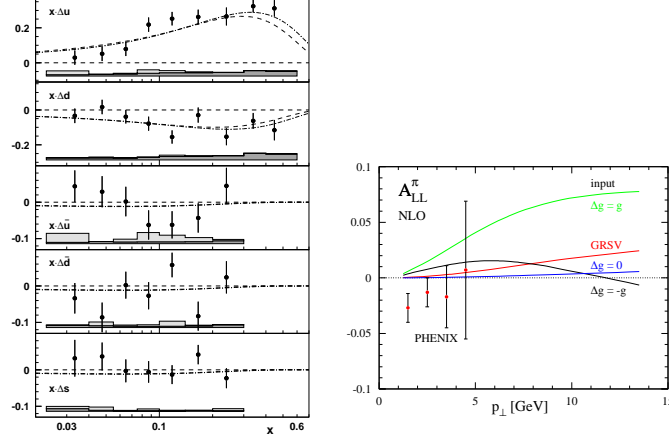
Figure 1.   Quark helicity distributions at $\langle Q^2 \rangle = 2.5 \, \text{GeV}^2$ from HERMES [7] (left panel), and longitudinal double spin asymmetry for $\vec{p}\vec{p} \to \pi^0 X$ from PHENIX [22] (right panel).

Measuring a parity-violating SSA in $\vec{p}p \to W^\pm X$ can provide complementary information on the helicity distribution of the light flavors [12,13], where for $W^+$ production one has

$$A_L^{W^+} = \frac{\Delta u(x_1)\bar{d}(x_2) - \Delta\bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)}. \tag{4}$$

Since $x_1$ and $x_2$ are fixed by external kinematics one can disentangle the contributions of the different flavors. If, e.g., $x_1$ is large, then both $\Delta\bar{d}$ and $\bar{d}$ are small and one can extract the ratio $\Delta u/u$. On the other hand the ratio $\Delta\bar{d}/\bar{d}$ can be obtained if $x_2$ is large. Analogously, production of $W^-$ allows one to measure $\Delta d/d$ and $\Delta\bar{u}/\bar{u}$. This method is rather clean and is planned to be exploited at RICH. Eventually, polarized neutrino DIS could be used to get additional information on $\Delta s$ and $\Delta\bar{s}$ [14].

## 2.2.  *Gluon helicity distribution*

In order to get information on the gluon helicity distribution $\Delta g$ of the nucleon one studies lepton nucleon scattering as well as $pp$-collisions, where different final states are considered in both cases.

In the DIS measurements one tries to isolate the partonic subprocess of photon-gluon fusion (PGF), $\gamma g \to q\bar{q}$. From the experimental point of view, inclusive DIS represents the simplest reaction containing PGF. However, since it only enters through evolution, this process merely provides a rather indirect measurement of $\Delta g$. Because of the limited range in $x$

4

and $Q^2$, the currently available data put no strong constraint on $\Delta g$, even though a positive $\Delta g$ is prefered in the analyses. This is in contrast to the situation of the unpolarized gluon distribution, where a lot of information is coming from unpolarized inclusive DIS which has been explored in a wide kinematical region.

A more direct measurement of the PGF process is possible by detecting high-$p_T$ jets or hadron pairs in the final state (see, e.g., Refs. 3–6 and referenes therein). In this context a special role is played by the production of a pair of charmed mesons created through $\gamma g \to c\bar{c}$, because background processes like the QCD-Compton reaction $\gamma q \to gq$ are automatically suppressed without making specific kinematical cuts. To measure $\Delta g$ via charm production is a central aim of the COMPASS Collaboration [15,16].

The only published numbers for $\Delta g$ from such type of reactions are coming from the production of high-$p_T$ hadron pairs. The measurements of the HERMES [17] and SMC [18] Collaborations, performed at different average values of $x$, yielded

$$\Delta g/g|_{\langle x \rangle = 0.17} = 0.41 \pm 0.18\,(\text{stat}) \pm 0.03\,(\text{syst}) \qquad (\text{from Ref. 17})\,, \quad (5)$$
$$\Delta g/g|_{\langle x \rangle = 0.7} = -0.20 \pm 0.28\,(\text{stat}) \pm 0.10\,(\text{syst}) \qquad (\text{from Ref. 18})\,. (6)$$

Unfortunately, these data are still suffering from large statistical errors. While the SMC result was obtained in the DIS regime ($Q^2 > 1\,\text{GeV}^2$), HERMES used photoproduction which led to speculations about background contributions from resolved photons.

The second class of processes providing information on $\Delta g$ are longitudinal double spin asymmetries in proton-proton collisions. To be specific, the following reactions are considered: prompt photon production ($\vec{p}\vec{p} \to \gamma X$), production of heavy flavors ($\vec{p}\vec{p} \to c\bar{c}X,\ b\bar{b}X$), jet production ($\vec{p}\vec{p} \to \text{jet}X$), as well as inclusive production of hadrons ($\vec{p}\vec{p} \to hX$). The processes have already been computed up to NLO in QCD. A detailed discussion of the advantages and drawbacks of the different reactions can be found in Refs. 13, 5, 19, 20, 21 and references therein. At RICH there are extensive ongoing activities in order to study the various channels for different kinematics.

The first published data are from the PHENIX Collaboration for inclusive production of neutral pions [22,23]. The asymmetry is shown in Fig.1 as function of the transverse momentum of the pion, and compared to a NLO calculation [19]. Measuring $A_{LL}^{\pi}$ with good statistics at higher values of $p_\perp$, where the sensitivity of the asymmetry to the gluon helicity is larger as compared to the low $p_\perp$ region, can already provide an important constraint on $\Delta g$.

## 3. Generalized parton distributions and orbital angular momentum

Knowing the helicity distributions is not sufficient to understand how the spin of the nucleon is decomposed. One also needs information on the orbital angular momentum of the partons. In 1996 it was shown [24] that generalized parton distributions (see, e.g., Refs. 25–29) can provide the pertinent information. GPDs appear in the description of hard exclusive processes like deep-virtual Compton scattering off the nucleon and meson production, where in both cases data have already been published (see Refs. 28, 30, 31 and references therein). Neglecting the scale dependence, GPDs are functions of three variables, $x$, $\xi$, $t$. While $\xi$ and $t$, describing the longitudinal and total momentum transfer to the nucleon, are fixed by the external kinematics of an experiment, $x$ is integrated over which complicates the extraction of the $x$-dependence of GPDs.

GPDs contain a vast amount of physics, and show several interesting properties which put strong constraints on models. They are related to forward parton distributions and nucleon form factors, obey the so-called polynomiality condition [32], and satisfy positivity bounds [33]. Moreover, they contain information on the shear forces partons experience in the nucleon [34]. In particular, they can provide a 3-dimensional picture of the nucleon [35].

Concerning the nucleon spin structure it is important that the total angular momentum (for longitudinal polarization) of quarks is related to the GPDs according to [24]

$$J_q^z = \frac{1}{2} \int_{-1}^{1} dx\, x \Big[ H_q(x, \xi, t = 0) + E_q(x, \xi, t = 0) \Big], \qquad (7)$$

where $H_q(x, 0, 0) = q(x)$, while the GPD $E_q$ has no relation to a normal forward distribution. For $J_g^z$ an analogous formula holds. Knowing both the total angular momentum and the helicity of partons allows one to address the orbital angular momentum by means of the decomposition

$$\frac{1}{2} = \sum_q J_q^z + J_g^z = \sum_q \left[ \frac{1}{2} \int_0^1 dx \Big( \Delta q(x) + \Delta \bar{q}(x) \Big) + L_q^z \right] + \Delta g + L_g^z. \ (8)$$

(Note that also for a transversely polarized nucleon a decomposition like in (8) has been proposed [36].) Recently, Lattice QCD [37,38] as well as models and phenomenlogical parametrizations of GPDs [39,40,41] were used to estimate the orbital angular momentum of the quarks. Lattice data, e.g., result in a small contribution to the angular momentum if one sums over the quarks, but the uncertainties of these calculations are still large.

6

## 4. Single spin asymmetries

Single spin asymmetries are currently under intense investigation from both the experimental and theoretical point of view. For the process $p^\uparrow p \to \pi X$, e.g., Fermi-Lab [42] observed large transverse SSAs (up to 40%) at the *cm*-energy $\sqrt{s} = 20\,\text{GeV}$, and recent results from the STAR Collaboration [43] have shown that the effect survives at $\sqrt{s} = 200\,\text{GeV}$ (see Fig.2). Also for pion production in semi-inclusive DIS non-vanishing transverse SSAs have been observed [44] (see Fig.2).

In general, SSAs are generated by so-called time-reversal odd (T-odd) correlation functions (parton distributions and fragmentation functions). They vanish in leading twist collinear factorization [45]. To get non-zero effects one has to resort to (collinear) twist-3 correlators [46,47] or to transverse momentum dependent functions [48,49,50]. There exist four T-odd leading twist TMD correlation functions, where the Sivers function $f_{1T}^\perp$ [51], describing the azimuthal asymmetry of quarks in a transversely polarized target, is the most prominent T-odd parton distribution. In the case of fragmentation the Collins function [52] (transition of a transversely polarized quark into an unpolarized hadron) has attracted a lot of interest, since in semi-inclusive DIS it gets coupled to the transversity distribution of the nucleon.

For $A_N$ in *pp*-collisions both TMD twist-2 and collinear twist-3 correlators were used to describe the data as can be seen in Fig. 2. For the twist-2 analysis, very recently the invoked kinematics has been revisited carefully. As a result it turns out that the Collins mechanism actually cannot explain the data [53], while the Sivers mechanism could well do so [54]. In contrast to $A_N$, in semi-inclusive DIS at low transverse momentum of the detected hadron one can unambiguously select the Sivers mechanism shown in Fig. 2.

For quite some time it was believed that T-odd TMD distributions like the Sivers function should vanish because of T-invariance of the strong interaction [52], whereas T-odd fragmentation functions may well exist because of final state interactions [52,55]. However, in 2002 a simple spectator model calculation provided a non-zero SSA in DIS [56]. A reanalysis then revealed that in fact the Sivers function can be non-zero, but only if the Wilson-line ensuring color gauge invariance is taken into account in the operator defintion [57]. The presence of the Wilson line which can be process-dependent in turn endangers universality of TMD correlation functions [57,58,59]. This problem affects also the soft factor appearing in factorization formulae for transverse momentum dependent processes. The schematical structure of
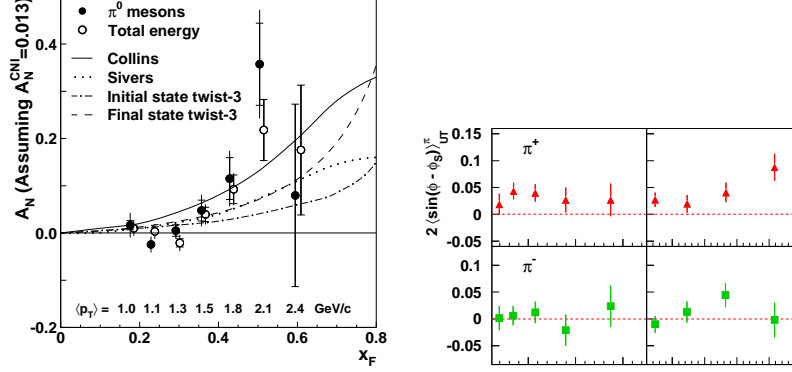
Figure 2.   Transverse single spin asymmetries: $A_N$ in $p^\uparrow p \to \pi^0 X$ from STAR [43] (left panel), and Sivers asymmetry in $ep^\uparrow \to e\pi X$ as function of $x$ (*lhs*) and $z$ (*rhs*) from HERMES [44](right panel).

the factorization formula for semi-inclusive DIS is [60,61,62]

$$\sigma_{DIS} \propto \text{pdf} \times \text{frag} \times \hat{\sigma}_{part} \times \text{soft} . \tag{9}$$

For unintegrated Drell-Yan and $e^+e^- \to h_1 h_2 X$ if the two hadrons are almost back-to-back one is dealing with corresponding formulae.  While time-reversal can be used to relate parton distributions in DIS which contain future-pointing Wilson lines to distributions in Drell-Yan with past-pointing lines, this is not possible for fragmentation functions. Nevertheless, by considering the analytic properties of the fragmentation correlator, it can be shown that fragmentation functions are universal [62,63]. This result, in particular, justifies to relate the Collins function in $e^+e^-$-annihilation and semi-inclusive DIS [64,65]. Also for the soft factor universality between the three mentioned processes can be established [62]. Only T-odd parton distributions are non-universal in the sense that they have a reversed sign in DIS as compared to Drell-Yan, i.e.,

$$\left. f_{1T}^\perp \right|_{DY} = - \left. f_{1T}^\perp \right|_{DIS} . \tag{10}$$

This relation should be checked experimentally.

There are many more interesting developments in the field of SSAs. For instance, a relation between the sign of the Sivers function and the anomalous magnetic moment of a given quark flavor was given [66]. Moreover, a sum rule relating the Sivers effect for quarks and gluons was derived [67]. It was also proposed to measure the gluon Sivers function through jet correlations in $p^\uparrow p$-collisions [68], and charm production ($p^\uparrow p \to DX$) [69].

8

## 5. Conclusions

We have briefly reviewed the status of the QCD spin structure of the nucleon. Currently, an enormous amount of activities is dealing with this vast and very interesting field.

Historically, the first subject which was studied intensely is the physics of parton helicity distributions, and today we already have a considerable knowledge about the quark helicity distribution. Uncertainties still exist in the strange quark sector and in the separation of valence and sea quark distributions, but many current activities are aiming at an improvement of this situation. In contrast to $\Delta q$, the gluon helicity distribution is still just weakly constrained. Nevertheless, a lot of new information, which is supposed to come in the near future from COMPASS and the various measurements at RHIC, will certainly increase our knowlegde about $\Delta g$.

Also generalized parton distributions can provide important information in order to resolve the spin puzzle of the nucleon, because the orbital angular momentum of partons is related to these objects. Using Lattice QCD as well as phenomenological approaches people have exploited this connection to determine the orbital angular momentum of quarks. At present, the situation is not yet conclusive, but should definitely improve in the future. In particular, many new preliminay data for hard exclusive reactions on the nucleon from COMPASS, HERMES, and Jefferson Lab exist. These data will also help to clarify the role played by orbital angular momentum in the spin sum rule of the nucleon.

The discovery that time-reversal odd parton distributions in general are non-zero gave a strong boost to the interesting subject of single spin asymmetries over the past three years. Since then a lot of progress has been made on both the theoretical but also the experimental side. In this context it has been a crucial discovery that the presence of the Wilson line in transverse momentum dependent correlation functions is mandatory. Because this field in some sense is still rather young, more fundamental results are to be expected. The large amount of already existing, preliminary, and forthcoming data from lepton-nucleon and proton-proton collisions will further improve our understanding of the origin of single spin asymmetries.

## References

1. R. Frisch and O. Stern, *Z. Phys.* **85**, 4 (1933).
2. V. Barone, A. Drago, and P. G. Ratcliffe, *Phys. Rep.* **359**, 1 (2002); V. Barone, these proceedings.
3. M. Anselmino, A. V. Efremov, and E. Leader, *Phys. Rep.* **261**, 1 (1995).

4.  B. Lampe and E. Reya, *Phys. Rep.* **332**, 1 (2000).
5.  B. W. Fillipone and X. Ji, *Adv. Nucl. Phys.* **26**, 1 (2001).
6.  S. D. Bass, hep-ph/0411005.
7.  HERMES Collaboration (A. Airapetian *et al.*), *Phys. Rev. Lett* **92**, 012005 (2003); hep-ex/0407032.
8.  D. Hasch, these proceedings; J. Rubin, these proceedings.
9.  A. Kotzinian, hep-ph/0410093; and these proceedings.
10.  E. Christova and E. Leader, *Nucl. Phys.* **B 607**, 369 (2001); E. Christova, these proceedings.
11.  A. N. Sissakian, O. Yu. Shevchenko, and O. N. Ivanov, hep-ph/04112243; O. Yu. Shevchenko, these proceedings.
12.  N. S. Craigie, K. Hidaka, M. Jacob, and F. M. Renard, *Phys. Rep.* **99**, 69 (1983); and references therein.
13.  G. Bunce, N. Saito, J. Soffer, and W. Vogelsang, *Ann. Rev. Nucl. Part. Sci.* **50**, 525 (2000).
14.  See, e.g., S. Forte, these proceedings.
15.  COMPASS proposal, CERN/SPSLC 96-14, SPSLC/P297, (1996); F. Bradamante, hep-ex/0411076.
16.  A. Bressan, these proceedings; C. Schill, these proceedings.
17.  HERMES Collaboration (A. Airapetian *et al.*), *Phys. Rev. Lett* **84**, 2584 (2000).
18.  SMC Collaboration (B. Adeva *et al.*), *Phys. Rev.* **D 70**, 012002 (2004); E. Rondio, these proceedings.
19.  B. Jäger, A. Schäfer, M. Stratmann, and W. Vogelsang, *Phys. Rev.* **D 67**, 054005 (2003).
20.  B. Jäger, S. Kretzer, M. Stratmann, and W. Vogelsang, *Phys. Rev. Lett* **92**, 121803 (2004).
21.  B. Jäger, M. Stratmann, and W. Vogelsang, *Phys. Rev.* **D 70**, 034010 (2004).
22.  PHENIX Collaboration (S. S. Adler *et al.*), *Phys. Rev. Lett* **93**, 202002 (2004).
23.  Y. Fukao, these proceedings; N. Saito, these proceedings; W. Vogelsang, these proceedings.
24.  X. Ji, *Phys. Rev. Lett.* **78**, 610 (1997).
25.  D. Müller, D. Robaschik, B. Geyer, F. M. Dittes, and J. Horejsi, *Fortsch. Phys.* **42**, 101 (1994).
26.  A. V. Radyushkin, *Phys. Rev.* **D 56**, 5524 (1997).
27.  K. Goeke, M. V. Polyakov, and M. Vanderhaeghen, *Prog. Part. Nucl. Phys.* **47**, 401 (2001).
28.  M. Diehl, *Phys. Rep.* **388**, 41 (2003).
29.  M. Garcon, these proceedings.
30.  HERMES Collaboration (A. Airapetian *et al.*), *Phys. Lett.* **B 599**, 212 (2004); R. Fabbri, these proceedings.
31.  CLAS Collaboration (C. Hadjidakis *et al.*), hep-ex/0408005.
32.  X. Ji, *J. Phys.* **G 24**, 1181 (1998).
33.  P. V. Pobylitsa, *Phys. Rev.* **D 65**, 114015 (2002).
34.  M. V. Polyakov, *Phys. Lett.* **B 555**, 57 (2003).

10

35.  M. Burkardt, *Int. J. Mod. Phys.* **A 18**, 173 (2003).
36.  B. L. G. Bakker, E. Leader, and T. L. Trueman, hep-ph/0406139; E. Leader, these proceedings.
37.  LHP Collaboration (P. Hägler *et al.*), *Phys. Rev.* **D 68**, 034505 (2003).
38.  QCDSF Collaboration (M. Göckeler *et al.*), *Phys. Rev. Lett.* **92**, 042002 (2004).
39.  M. Diehl, T. Feldmann, R. Jakob, and P. Kroll, hep-ph/0408173.
40.  M. Guidal, M. V. Polyakov, A. V. Radyushkin, and M. Vanderhaeghen, hep-ph/0410251.
41.  J. Ossmann, M. V. Polyakov, P. Schweitzer, D. Urbano, and K. Goeke, hep-ph/0411172.
42.  E704 Collaboration, (D. L. Adams *et al.*), *Phys. Lett.* **B 264**, 462 (1991).
43.  STAR Collaboration, (J. Adams *et al.*), *Phys. Rev. Lett.* **92**, 171801 (2004); A. Ogawa, these proceedings.
44.  HERMES Collaboration, (A. Airapetian *et al.*), hep-ex/0408013; G. Schnell, these proceedings.
45.  G. L. Kane, J. Pumplin, and W. Repko, *Phys. Rev. Lett.* **41**, 1689 (1978).
46.  A. V. Efremov and O. V. Teryaev, *Phys. Lett.* **B 150**, 383 (1985).
47.  J. Qiu and G. Sterman, *Phys. Rev. Lett.* **67**, 2264 (1991).
48.  J. P. Ralston and D. E. Soper, *Nucl. Phys.* **B 152**, 109 (1979).
49.  P. J. Mulders and R. D. Tangerman, *Nucl. Phys.* **B 461**, 197 (1996).
50.  D. Boer and P. J. Mulders, *Phys. Rev.* **D 57**, 5780 (1998).
51.  D. W. Sivers, *Phys. Rev.* **D 41**, 83 (1990); *Phys. Rev.* **D 43**, 261 (1991).
52.  J. C. Collins, *Nucl. Phys.* **B 396**, 161 (1993).
53.  M. Anselmino, E. Boglione, U. D'Alesio, E.Leader, and F. Murgia, hep-ph/0408356; U. D'Alesio, these proceedings.
54.  U. D'Alesio and F. Murgia, *Phys. Rev.* **D70**, 074009 (2004); F. Murgia, these proceedings.
55.  A. Bacchetta, R. Kundu, A. Metz, and P. J. Mulders, *Phys. Lett.* **B 506**, 155 (2001).
56.  S. J. Brodsky, D. S. Hwang, and I. Schmidt, *Phys. Lett.* **B 530**, 99 (2002).
57.  J. C. Collins, *Phys. Lett.* **B 536**, 43 (2002).
58.  D. Boer, P. J. Mulders, and F. Pijlman, *Nucl. Phys.* **B 667**, 201 (2003).
59.  C. J. Bomhof, P. J. Mulders, and F. Pijlman, *Phys. Lett.* **B 596**, 277 (2004); F. Pijlman, these proceedings.
60.  J. C. Collins and D. E. Soper, *Nucl. Phys.* **B 193**, 381 (1981).
61.  X. Ji, J. Ma, and F. Yuan, hep-ph/0404183; *Phys. Lett.* **B 597**, 299 (2004).
62.  J. C. Collins and A. Metz, hep-ph/0408249.
63.  A. Metz, *Phys. Lett.* **B 549**, 139 (2002).
64.  A. V. Efremov, K. Goeke, and P. Schweitzer, *Phys. Lett.* **B 522**, 37 (2001).
65.  R. Seidl, these proceedings.
66.  M. Burkardt, *Phys. Rev.* **D 66**, 114005 (2002).
67.  M. Burkardt, *Phys. Rev.* **D 69**, 091501 (2004).
68.  D. Boer and W. Vogelsang, *Phys. Rev.* **D 69**, 094025 (2004).
69.  M. Anselmino, E. Boglione, U. D'Alesio, E.Leader, and F. Murgia, *Phys. Rev.* **D70**, 074025 (2004); E. Boglione, these proceedings.